BRIEF COMMUNICATIONS

SUCCESSFUL ENDOSCOPIC CORONARY ARTERY BYPASS GRAFTING: AN ACUTE LARGE ANIMAL TRIAL

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Significant technologic advances over the past decade have allowed for the development of minimally invasive endoscopic operative techniques in a variety of surgical disciplines. These endoscopic procedures have reduced cost, patient morbidity, and length of hospital stay. Over the past few years, minimally invasive direct coronary artery bypass has been reintroduced into the arena of cardiac surgery, with encouraging short-term results.^{1,2} However, performing the anastomosis is more technically challenging, and access to anastomotic targets is limited. To overcome some of these shortcomings, Port-Access cardiac surgery (Heartport, Inc, Redwood City, Calif) was introduced.³ This approach still requires an incision. Thus the goal of a completely endoscopic coronary artery bypass grafting (CABG) procedure has not yet been realized.

Recently, robotics have been developed to assist in endoscopic suturing, and these devices have been demonstrated to enhance surgical dexterity during a microvascular anastomosis.^{4,5} The purpose of this study was to determine the feasibility of using a robotically assisted microsurgical system to perform coronary artery anastomoses in an acute large animal model.

Methods

Preparation of animal. Holstein calves weighing 80 to 95 kg were used in the study. The animals were anesthetized with 6 to 8 mg/kg of intravenous methohexital and isoflurane and intubated, and mechanical ventilation was begun. Arterial and venous access was established for continuous temperature and pressure monitoring. The carotid artery was isolated in the left side of the neck and used for arterial cannulation for cardiopulmonary bypass.

A 3-cm left subcostal incision was made, and the distal portions of the left internal thoracic artery (ITA) and vein were identified and ligated. A small window was created in the diaphragm, and the distal, transected ends of the vessels were placed into the chest. A 10-mm endoscopic port (Endopath,

Ethicon, Inc, Somerville, NJ) and a 30-degree 10-mm endoscope (Karl Storz, Culver City, Calif) were placed to the right of the xiphoid process. A 5-mm grasper and endoscopic electrocautery (Surgiwand; United States Surgical Corporation, Norwalk, Conn) were placed through the subcostal incision for endoscopic dissection of the left ITA. The left ITA was harvested endoscopically (average time, 118 ± 9 minutes).

Cardiopulmonary bypass. A right thoracotomy was performed in the fourth intercostal space. The right ITA was exposed at the anterior limit of the thoracotomy for ultrasonic flow measurements. After systemic heparinization, the carotid artery was cannulated for arterial inflow. The right atrium was then cannulated with a 2-stage venous cannula (Medtronic DLP, Grand Rapids, Mich).

Cardiopulmonary bypass was then instituted. The hemiazygos vein was ligated; a 16F vent was placed in the apex of the heart, and a catheter was placed in the proximal ascending aorta for cardioplegia delivery. The left ITA free flow was measured. The calves were systemically cooled to 30°C to 32°C. The aorta was crossclamped, and antegrade hyperkalemic crystalloid cardioplegic solution was delivered.

Robotic anastomosis. A 0-degree endoscope (Karl Storz) was passed through the 10-mm port and connected to a voice-controlled robotic camera holder (Aesop 3000; Computer Motion, Goleta, Calif). Two 5-mm endoscopic ports were placed subcostally, 7 cm on either side of the endoscope, for use with the robotic instruments. The Zeus Robotic Microsurgical System (Computer Motion) consisted of 2 robotic arms that manipulate modified endoscopic instruments (Fig 1). The surgeon controlled these instruments by manipulating specially designed handles. These surgical controls allowed for 4 full ranges of motion (pan, roll, tilt, and in/out) and grasping. The surgeon's motions were directly and precisely translated to the robotic arms by a computer control system. Custom-designed software allowed for tremor elimination and scaling on a range from 2:1 to 10:1.

After cardioplegic arrest, an arteriotomy was made endoscopically in the distal left anterior descending coronary artery with robotically controlled scissors. A continuous end-to-side anastomosis was performed endoscopically with the robotic instruments with a specially designed 6-cm double-armed 7-0 polytetrafluoroethylene suture.* On completion of the anasto-

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*Gore-Tex suture; registered trade name of WL Gore & Associates, Inc, Flagstaff, Ariz.

Fig 1. The Zeus microsurgical robotic system in position during an acute bovine case. The robotic arm holding the camera is in the middle; the 2 arms holding the surgical instruments are on each side. All 3 ports are placed subcostally.

Fig 2. Postmortem angiogram shows left ITA to left anterior descending graft patency.

mosis, the hearts were reperfused for 1 hour. The animals were weaned from bypass, and ultrasonic flow measurements (HT 311; Transonic Systems Inc, Ithaca, NY) were obtained for both the right ITA and left ITA. The animals were sacrificed, and the hearts were rapidly excised for pathologic fixation.

Results

Acute hemodynamic results. All 6 animals in the study underwent successful endoscopic CABG and were weaned

from bypass without inotropic support. The mean crossclamp time was 48.7 ± 2.4 minutes. The mean time to completion of the anastomosis, including arteriotomy and knot tying, was 35.8 ± 1.8 minutes. For reference, blood flow in the in situ right ITA was 48.0 ± 10.7 mL/min on cardiopulmonary bypass and 72.0 ± 15.0 mL/min on weaning from bypass. The left ITA to left anterior descending blood flow was 41.9 ± 11.0 mL/min on bypass and 84.0 ± 13.6 mL/min after the animals had been completely weaned from bypass.

Angiographic and histologic examination. Angiograms and pathologic examinations were performed on all the excised, fixed hearts before pathologic examination. All of the anastomoses were observed to be patent and without stenosis or leak on angiogram (Fig 2). Gross pathologic examination revealed routine postoperative changes without evidence of other abnormalities. Dissection of the left coronary arteries and ITA grafts revealed patent grafts with no thrombi. Microscopic examination revealed all anastomoses to be patent and free of thrombi.

Discussion. Despite recent advances in minimally invasive cardiac surgery, the goal of completely endoscopic CABG has not yet been realized clinically. Recently, robotic instrumentation has been introduced into the operating room in the form of robotic camera holders for endoscopic operations. Further technologic advances have enabled the development of robotics that control surgical instruments.^{4,5} It was our hypothesis that robotic instrumentation may allow the surgeon to operate precisely in confined spaces and enable endoscopic CABG.

The current study demonstrates that endoscopic CABG with robotically assisted instrumentation is technically feasible in an intact large animal model with excellent graft patency. The robotic microsurgical system was able to eliminate

tremor through motion filtering, thus enhancing surgical precision. This tremor elimination and computer motion scaling overcome perhaps the most significant limitation of conventional endoscopic instruments. Although further chronic studies are necessary to fully validate the clinical utility of this robotic instrumentation, the current study provides encouraging preliminary results. Robotic assistance in the microsurgical environment may allow for the development of completely endoscopic CABG.

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EXTRACARDIAC CAVOPULMONARY CONNECTION OF FONTAN PROCEDURE WITH AUTOLOGOUS PEDICLED PERICARDIUM WITHOUT CARDIOPULMONARY BYPASS

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Total cavopulmonary connection has been proposed as a rational alternative to atriopulmonary connection for complex Fontan operation. The extracardiac conduit technique has gained favor because it streamlines the venous flow pattern and reduces the incidence of atrial arrhythmias. Unfortunately, extracardiac conduits with prosthetic tube grafts have no potential for growth, so their application in extremely young children may not be warranted.

Hvass and associates¹ have reported bicaval pulmonary connection in tricuspid atresia with an extracardiac tube of autologous pedicled pericardium to bridge the inferior vena cava (IVC) to the pulmonary artery. Pedicled pericardial tubes may be an attractive vascular substitute for right heart bypass. This nonthrombogenic material retains its growth potential and has shown its ability to allow unrestricted flow from the IVC to the right pulmonary artery.

A 7-month-old boy with a single right ventricle, transposition of the great arteries, and pulmonary stenosis underwent extracardiac Fontan operation with the use of a pedicled peri-

autologous pedicled
pericardial roll (18 × 70 mm)

Fig 1. Autologous pedicled pericardial roll (18 × 70 mm) was made.

cardial roll between the IVC and the right pulmonary artery without cardiopulmonary bypass.

Clinical summary. The patient initially underwent a balloon atrial septectomy. Cyanosis gradually improved after that. At an age of 2 years and 8 months and body weight of

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